Managing the Extreme Risks of Deep Space Exploration

Panel 06C - RAMS 2017

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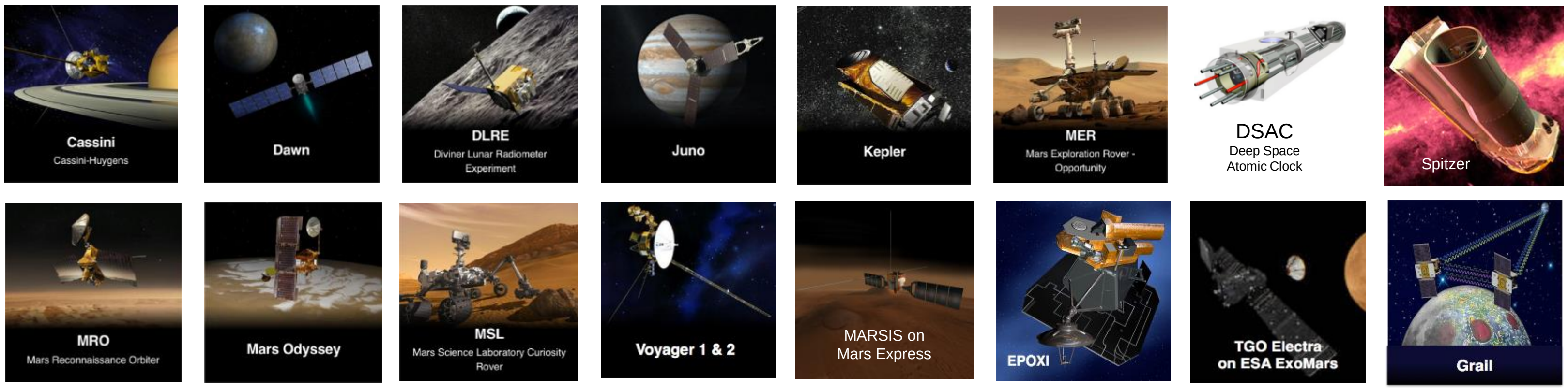
NASA/Caltech Jet Propulsion Laboratory (JPL)

- JPL is the lead NASA Center for the robotic exploration of the solar system… and beyond
- An FFRDC managed by Caltech
- NASA assigns us high risk missions that have never before been attempted

JPL invents products where we may make only a single unit, which may cost a billion dollars, that is designed to go somewhere previously unreachable.

Current JPL Spaceflight Projects

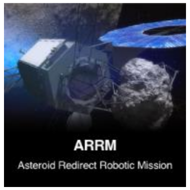
Deep Space Missions

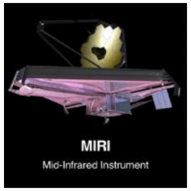


Earth Orbiting Missions

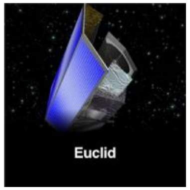
JPL Spaceflight Projects in Development

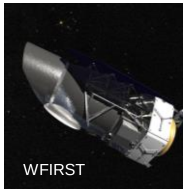
Deep Space Missions

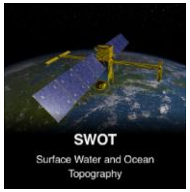


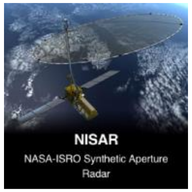


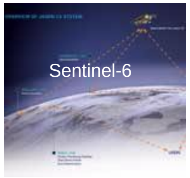
Earth Orbiting Missions









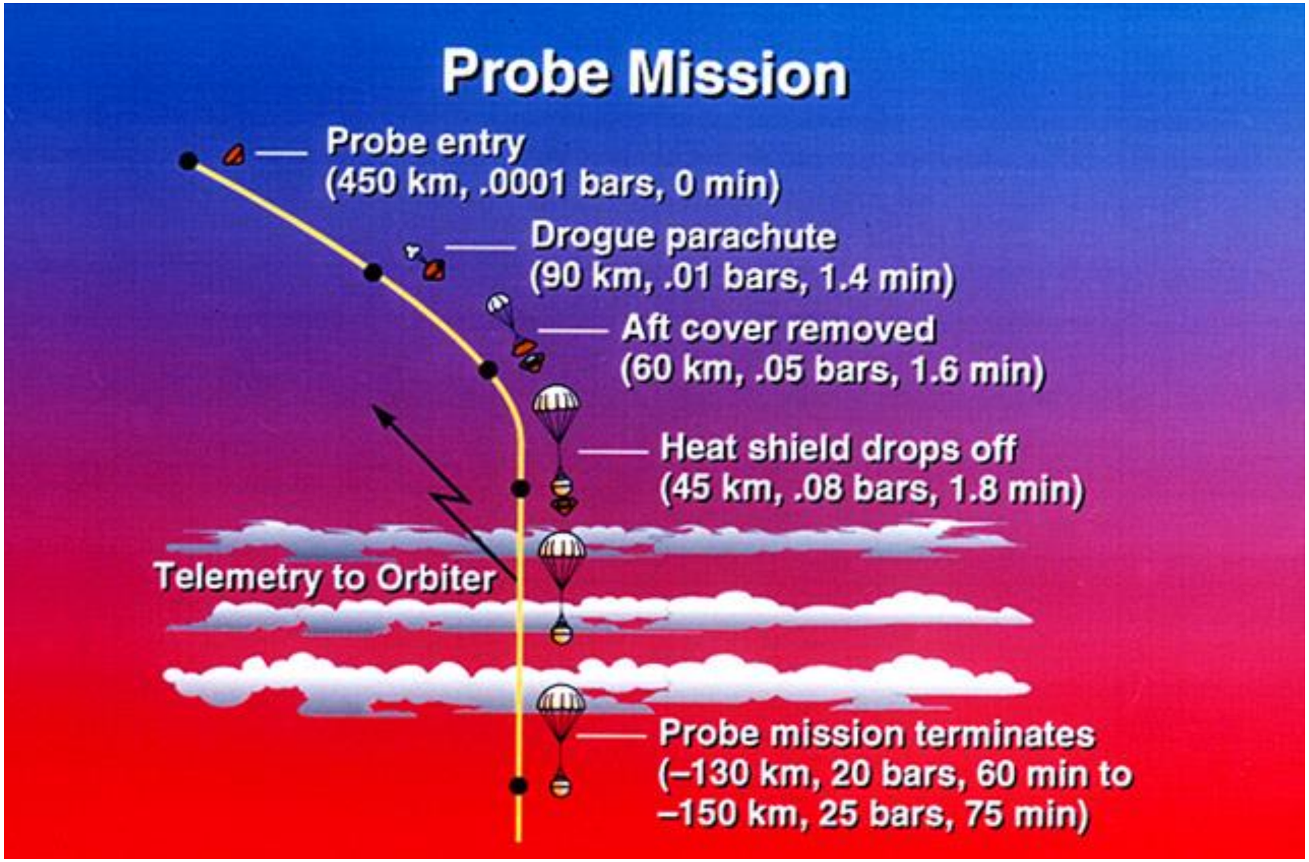


Extreme Risk → Extreme Engineering

- **JPL systems**: often one-of-a-kind, high unit value, that must operate with precision in an extremely hostile environment
  - **Deep Impact** (2005): An optically navigated flying copper “bullet” ran head-on into a comet while being tracked on the mother ship, all autonomously

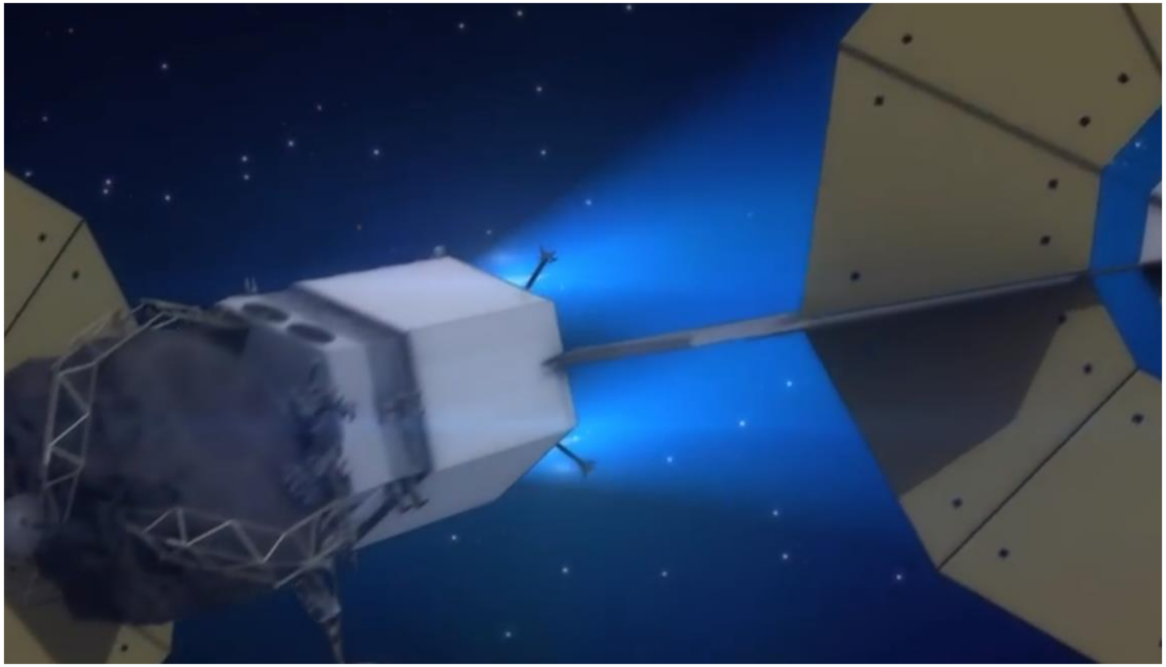
Another Extreme Engineering Example

- Galileo Jupiter Probe



Another Extreme Engineering Example

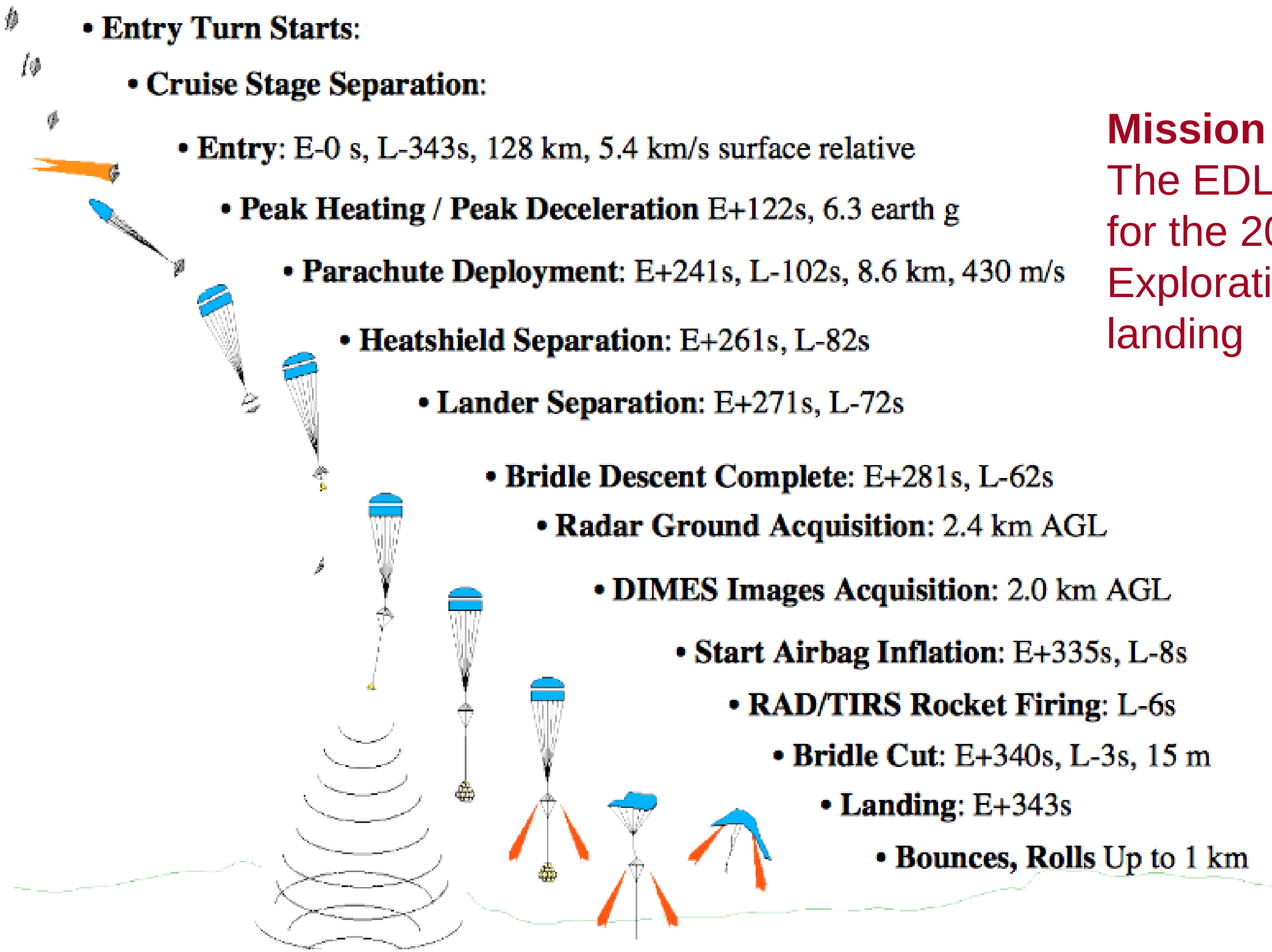
- **Asteroid Redirect Mission** would demonstrate the electric propulsion technology that may also be needed to deliver heavy cargo (i.e., supplies) to Mars, pre-positioning them for a crewed Mars mission, and maybe even bringing the crew.



Extreme Risk Challenges to the Design

- Spacecraft face environments unique to space
  - Zero gravity, solar energetic particles, micrometeoroid/space debris, vacuum, thermal environment, vibroacoustics, etc.
- Spacecraft face failure modes unique to spaceflight
  - Single event effects/upsets, total radiation dose, surface degradation, electrostatic charging/discharge, plasma interference, over/under heating, thermal cycling, etc.
- Potential failure modes are not time-dependent
  - Cruise phase (e.g., 7-yr Cassini) mostly dormant/benign
  - Most risk typically centered in significant events (e.g., deployments, landings) that may last only minutes
- Reliability of complex spacecraft and missions
  - >60 pyros must fire in precise sequence during Mars landing

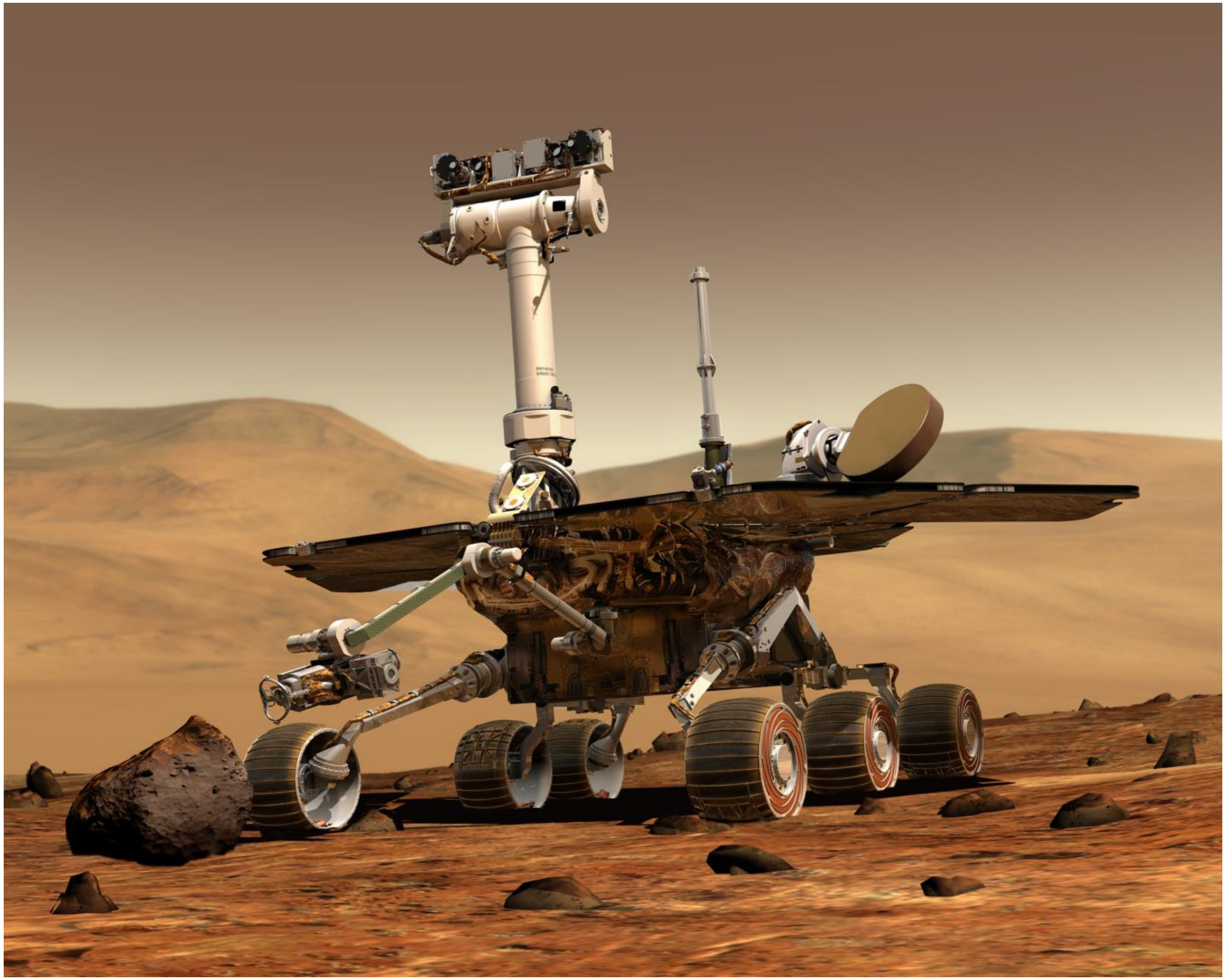
Mars Entry, Descent, and Landing (EDL)



Mission Complexity:
The EDL sequence for the 2004 Mars Exploration Rover landing

Design Challenge from Highly Unique Missions

- Mars Exploration Rovers: “Spirit” & “Opportunity”

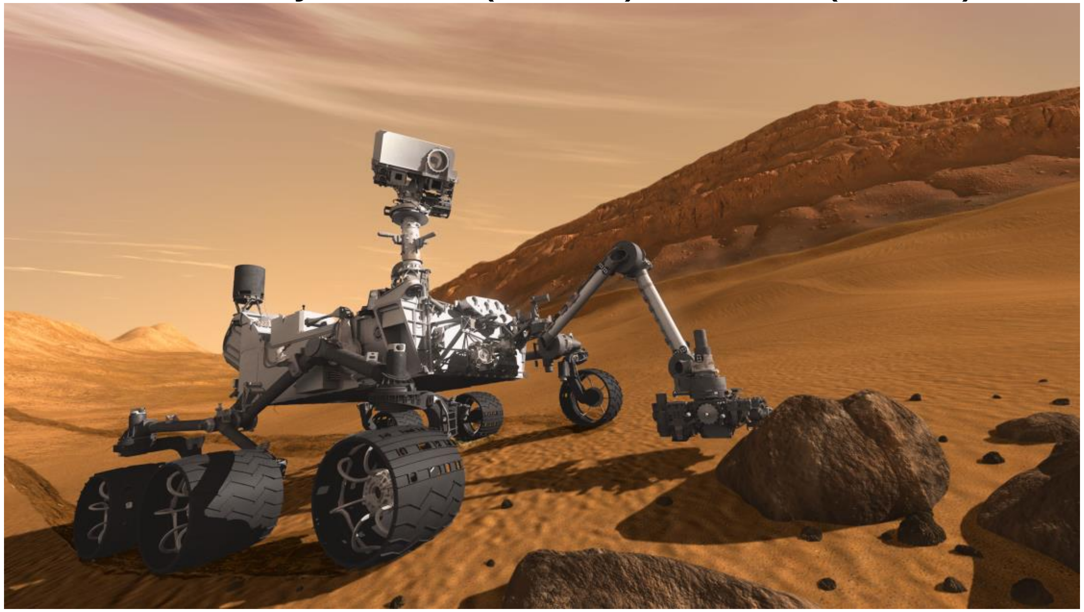


Risk Necessitates Extreme Innovation

- Curiosity rover was too massive to land on airbags, hence “sky crane” design solution

- Best design solution for desired year-around, 30 degree N/S latitude, operation was radioisotope power

Curiosity lander (above) & rover (below)



Design for Environmental Extremes & Uncertainty

- Mars has a hostile environment in terms of pressure, temperature extremes, thermal cycling, radiation, winds, dust, terrain (rocks, cliffs, quicksand)– it's also uncertain
  - Design must encompass uncertainty/worst case environment
  - Winds could have damaged Spirit rover on landing

<u>Sensor was added</u>: 3 photos taken seconds before landing so transverse thrusters could counteract winds/ground speed over Gusev Crater's sharp rocks

- The two Mars Exploration Rovers' design life was 90 days
  - But the "Spirit" rover lasted 6 years
  - And the "Opportunity" rover is still active after 13 years

TOMORROW

So How Do We Mitigate Risk?

- "Preventions"
  - Robust design (e.g., margins), redundancy, fault tolerance, fault detection & recovery, thermal control, design rules
- Analyses
  - Structural stress, reliability (FTA, FMEA, PSA, WCA, SCA), software safety/reuse, peer reviews, modeling (thermal, radiation, micrometeoroid, 3D), pyroshock, IESD, RVA
  - Active risk assessment/mgmt throughout the project lifecycle
- Controls
  - Quality assurance, vendor inspection, materials/parts selection, verification & validation, engineering standards
- Test, Test, Test!
  - Technology qualification, assembly testing, system-level testing, life testing, mission simulation (testbed)

Emerging Engineering Challenges/Risks

- Increasing complexity
  - Trend toward higher spacecraft complexity (e.g., more science instruments) and mission complexity (e.g., multiple flybys, complex trajectories, surface ops, s/c repurposing)
  - Trade of h/w functions implemented in s/w; s/w in h/w (FPGAs)
- Engineering limits (i.e., the laws of physics)
  - e.g., decelerating massive Martian spacecraft, shipping supplies to Mars, extended operability

- Verification and Validation
  - How do you verify 10,000 requirements?
  - Or, how do we redefine our systems engineering processes to make verification/validation more efficient and effective?
- Retaining and sharing critical “how-to” knowledge
  - The “silver tsunami”